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(54) Acoustic transducers.

(57) An acoustic transducer, such as a headphone 2, comprises a housing with a vent 16 for venting fluid medium from the housing. The vent is dimensioned to ensure that laminar flow of the fluid medium through the vent 16 is maintained throughout the working range of the drive unit 14 of the transducer so that the amplitude response and phase response of the transducer are substantially invariant throughout the working range of the drive unit 14.

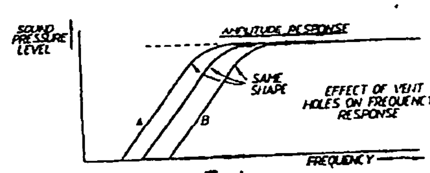

FIG.1.

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ACOUSTIC TRANSDUCERS

The present invention relates to acoustic transducers.

There are many kinds of acoustic transducers such as, for example, loudspeakers, earphones, microphones, hydrophones or underwater sound generators. As a result of an increase in interest in electroacoustic systems there is an increasing demand for acoustic transducers, and in particular to earphones which are acoustically coupled to the human ear, which exhibit an invariant phase response over a wide range of drive levels. Phase response is defined as the phase change between the transducer output at the diaphragm and the applied signal against frequency.

Acoustic transducers also exhibit amplitude response which, in sound producing acoustic transducers, is the sound pressure level that the drive unit in the transducer can generate when a drive voltage is applied to it against frequency. However, acoustic transducers exhibit a causal relationship between the phase response and the shape of the amplitude response. In earphones, for example, the amplitude response is not always directly proportional to the electrical drive level; that is, the earphones do not exhibit an invariant amplitude response shape. The non-linear amplitude response of earphones is particularly evident at low frequencies and high drive levels and usually gives rise to considerable distortion when these conditions prevail.

It is an object of the present invention to provide an acoustic transducer having an invariant phase response and an invariant amplitude response shape.

Accordingly, there is provided an acoustic transducer for use in a bulk of a fluid medium, the transducer comprising a housing defining a cavity containing the fluid medium, a drive unit mounted in the housing, and vent means providing a leak path, for venting the fluid medium from the cavity, dimensioned for maintaining a substantially laminar flow of the fluid medium through the vent means throughout the working range of the drive unit such that the amplitude response shape and the phase response of the transducer are substantially invariant throughout the working range of the drive unit.

The housing may define a further cavity containing the fluid medium and has a wall common to both cavities and the drive unit is mounted on the wall common to both cavities.

The vent means may provide a leak path from either one or both of the cavities to the bulk of the fluid medium or may provide a leak path between the two cavities or any combination thereof.

The vent means may be located on the wall of the housing common to both cavities.

The vent means may comprise a plurality of holes.

The vent means may comprise a single hole containing a fibrous material to provide a plurality of leak paths through the vent means.

The fibrous material may comprise wool, sintered glass, metal, or plastics material.

The vent means may comprise a plurality of holes etched in a plate of photosensitive material.

The photosensitive material may comprise glass.

The holes may be formed in a distributed manner around the housing defining the cavity or close together at a particular location of the cavity.

The acoustic transducer may comprise a loudspeaker, earphone, microphone, hydrophone, or underwater sound generators.

The present invention will now be described, by way of example, with reference to the accompanying drawings in which:

Figure 1 illustrates a graph showing the amplitude response of an earphone of known design and the effect of providing a vent hole from the front cavity to either the bulk of the fluid or the rear cavity when fluid flow is laminar in an earphone;

Figure 2 illustrates a graph showing an example of the amplitude responses of an earphone of known design at various drive levels;

Figure 3 illustrates a graph showing an example of the phase response of an earphone of known design at various drive levels; and

Figures 4 and 5 illustrate a schematic cross-sectional view of an earphone in accordance with the present invention.

Referring to Figure 1, it is known to provide a leak hole in either the front or rear cavity of an earphone. The effect of the leak hole is to roll off the low frequency response of the earphone, an increase in the leak hole size causing a decrease in the sensitivity of the earphone to low frequency signals. Hence, in Figure 1 an increase in the leak hole size when fluid flow is laminar will cause the low frequency response of the transducer to change from that shown in response A to that shown in response B. The main reason for providing the leak hole is to allow for ambient pressure changes.

From Figure 2 it can be seen that the earphone does not exhibit an invariant amplitude response shape as the amplitude response at low frequencies with an applied drive level of 4V differs from that obtained for applied drive levels of ½V, 1V and 2V.

The low frequency phase response of an earphone is determined by the acoustic leak in the earphone cavities. A particular leak hole size is required to achieve a desired low frequency phase response but this desired phase response will only be invariant for drive levels up to a certain critical value, as shown in Figure 3.

Referring to Figures 4 and 5, an acoustic transducer in the form of an earphone 2 comprises a housing which forms an earshell 4. The earshell 4 has a cushion 6 fixed peripherally at the open end thereof such that when the earphone 2 is worn by a user the earshell 4, in conjunction

with a partition 8 defines a front cavity 10 and a rear cavity 12. A drive unit 14 is mounted on the partition 8 and may be connected to a drive level signal source.

The earshell 4 is provided with vent means which, in the embodiment shown in Figure 4 comprises a plurality of holes 16, and in the embodiment of Figure 5 comprises a hole 18 containing a plug 20 of fibrous material.

The vent means provides a leakage path for fluid medium contained within the front cavity 10 to a bulk of the fluid which surrounds the exterior of the earshell 4.

When an electrical signal is applied to the drive unit 14 a diaphragm (not shown) is caused to vibrate at a frequency corresponding to the electrical signal. The vibration of the diaphragm causes sound to be generated in the fluid medium contained in the front and rear cavities 10 and 12. The sound generated in the front cavity 10 will cause a pressure difference between the fluid medium in the front cavity 10, and the bulk of the fluid medium exterior to the earshell 4 which produces a flow of the fluid medium through the holes 16 or 18.

In developing the earphone of the present invention it was determined that in known earphone designs the fluid flow through the leak hole is laminar at low drive levels but at higher drive levels the fluid flow becomes turbulent, resulting in a greater impedance to the flow of fluid through the leak hole and a variant phase response for the earphone, that is, the phase response changes with

drive level when the fluid flow in the leak hole is turbulent.

The earphone of the present invention, as shown in Figures 4 and 5 has the vent means dimensioned to permit substantially laminar flow of the fluid medium from the front cavity 10 through the holes 16 and 18 throughout the working range of the drive unit 14; that is, up to the maximum drive level of the drive unit 14. Hence, the earphone 2 can be designed to have a required low frequency amplitude response shape and an invariant phase response up to the highest sound pressure level that the earphone can generate.

This is achieved by replacing the single leak hole in known designs with vent means in the form of a plurality of holes that are either longer in effective length than the single leak hole or have smaller radii, or both. This permits the flow of fluid medium to remain substantially laminar with a larger pressure difference across the holes. The vent means may be fabricated either by providing a plurality of holes 16 in the earshell, as shown in Figure 4, or by the use of a single hole 18 containing a plug 20 of material which allows a multiplicity of long thin fluid paths to be formed in the single hole 18 as shown in figure 5. Suitable materials for the plug 20 are, for example, wool, glass or wire wool, sintered glass, metal or plastics material. Alternatively the holes may be fabricated by etching holes in a photosensitive material, such as glass, which may form a panel in the earshell 4.

Individual holes may be drilled in a distributed manner in the earshell 4 or in a particular localised area of the earshell and different types of material may be inserted into the holes to form the plugs 20.

For any cylindrical hole size and sound pressure, fundamental fluid flow theory may be applied to determine whether the flow of the fluid medium through the vent means is laminar or turbulent via the use of Reynolds' Condition. Laminar flow occurs if

$$\frac{r^3 p \rho}{4\eta^2 L} \quad \text{Reynolds' Number (a constant)} \quad \ldots\ldots\ldots(i)$$

where r is the radius of the hole

p is the pressure difference across the hole

η is the viscosity of the fluid medium

L is the length of the hole

and ρ is the density of the fluid

From Reynolds' Condition it can be seen that the flow of a fluid through a hole will be laminar up to a higher pressure difference if the hole is either of longer length or has a smaller radius or both. The maximum value for equation (i) above is when fluid flow starts to occur through the hole where the value for the pressure difference p is largest. If Reynolds' condition is applied with this pressure value it can be determined whether or not the fluid flow in any hole will be turbulent.

If it is determined that, for given parameters, the flow of fluid in the hole is turbulent, the dimension of the hole can be changed either to be longer in length, or have a smaller radius, or both, such that laminar flow of the fluid in the hole is maintained.

However, as a result of changing the dimensions of the hole to satisfy Reynolds' Condition the volume rate of the fluid medium leaking from the cavity will be reduced, resulting in a different phase response.

The volume rate of the fluid flow (V) through a cylindrical hole obeys Poiseuille's Law, whereby

$$V = \frac{r^4 p}{8\eta L} \quad \ldots\ldots\ldots\ldots\ldots \text{(ii)}$$

where the letters represent the same parameters as those used in equation (i). Therefore, it can be seen from equation (ii) that to maintain the same fluid throughput more holes can be used which are either longer in length or have smaller radii or both.

By applying equations (i) and (ii) above the holes can be designed to have dimensions which provide the earphone with a phase response which is invariant up to the maximum drive level of the drive unit in the earphone as laminar flow of the fluid medium from the cavity 10 through the holes 16 or 18 can be maintained up to the maximum sound pressure level that the earphone is able to generate.

It is important to realise that, as an earphone

utilising this invention will exhibit an invariant phase response and amplitude response shape throughout its working range, the distortion produced by the earphone at low frequencies will be much lower than current designs of earphones: current earphone designs exhibit amplitude responses which are drive level dependant at high drive levels, that is, non linear behaviour, which gives rise to high levels of distortion.

Although the present invention has been described with reference to a particular embodiment, it is to be understood that modifications can be effected within the scope of the invention. For example, the present invention may comprise any type of drive unit in any design of acoustic transducer which has only a front or rear cavity and where fluid leaks can be introduced. Furthermore, although the vent means has been shown connecting the fluid medium within the front cavity to the bulk of the fluid medium surrounding the earshell, the holes forming the vent means may connect either the front or rear cavities, or both the front or rear cavities or to the bulk of the fluid medium, or any combination. Moreover acoustic transducers according to the present invention may comprise loudspeakers, earphones, microphones, hydrophones and underwater sound generators.

CLAIMS

1. An acoustic transducer for use in a bulk of a fluid medium, the transducer comprising a housing defining a cavity (12) containing the fluid medium, a drive unit (14) mounted in the housing, and vent means (16, 18) providing a leak path, for venting the fluid medium from the cavity, characterised in that the vent means (16, 18) is dimensioned for maintaining a substantially laminar flow of the fluid medium through the vent means (16, 18) throughout the working range of the drive unit (14) such that the amplitude response shape and the phase response of the transducer are substantially invariant throughout the working range of the drive unit.

2. An acoustic transducer according to claim 1 characterised in that the housing defines first and further cavities (10, 12) containing the fluid medium and the drive unit (14) is mounted on a wall (8) common to both cavities (10, 12).

3. An acoustic transducer according to claim 2 characterised in that the vent means (16, 18) is arranged to provide a leak path from either one or both of the cavities (10, 12) to the bulk of the fluid medium.

4. An acoustic transducer according to claim 2 characterised in that the vent means (16, 18) is arranged to provide a leak path between the first and the further cavities (10, 12).

5. An acoustic transducer according to claim 4 characterised in that the vent means (16, 18) is arranged in the wall (8) of the housing common to both cavities (10, 12).

6. An acoustic transducer according to any one of claims 1 to 5 characterised in that the vent means (16) comprises a plurality of holes dimensioned for maintaining a substantially laminar flow of the fluid medium therethrough.

7. An acoustic transducer according to any one of claims 1 to 5 characterised in that the vent means (18) comprises a single hole (18) containing a fibrous material (20) to provide a plurality of leak paths through the vent means (18) arranged for maintaining a substantially laminar flow of the fluid medium therethrough.

8. An acoustic transducer according to claim 7 characterised in that the fibrous material (20) comprises wool.

9. An acoustic transducer according to claim 7 characterised in that the fibrous material (20) comprises sintered glass, metal or plastics material.

10. An acoustic transducer according to claim 6 characterised in that the vent means (16) comprises a plate of photosensitive material having a plurality of holes etched therein.

11. An acoustic transducer according to claim 10 characterised in that the photosensitive material comprises glass.

12. An acoustic transducer according to claim 6 characterised in that the plurality of holes are formed in a distributed manner around the housing.

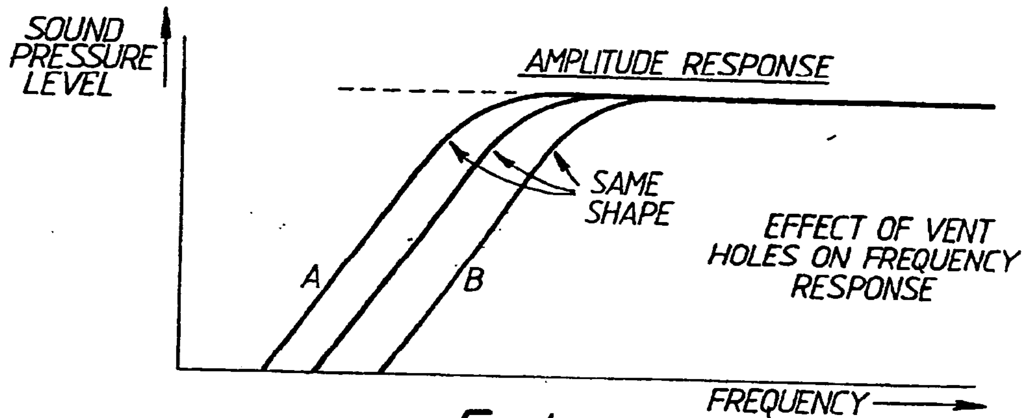

FIG. 1.

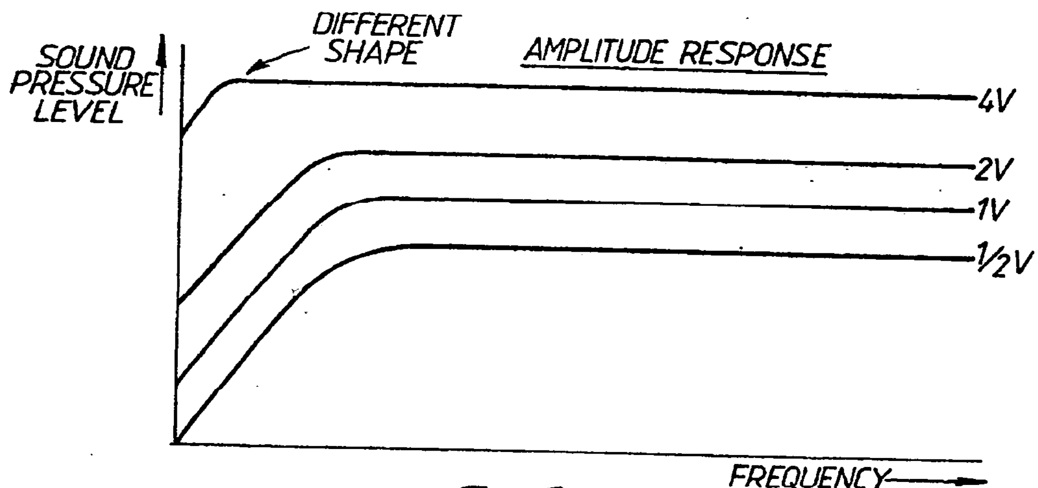

FIG. 2.

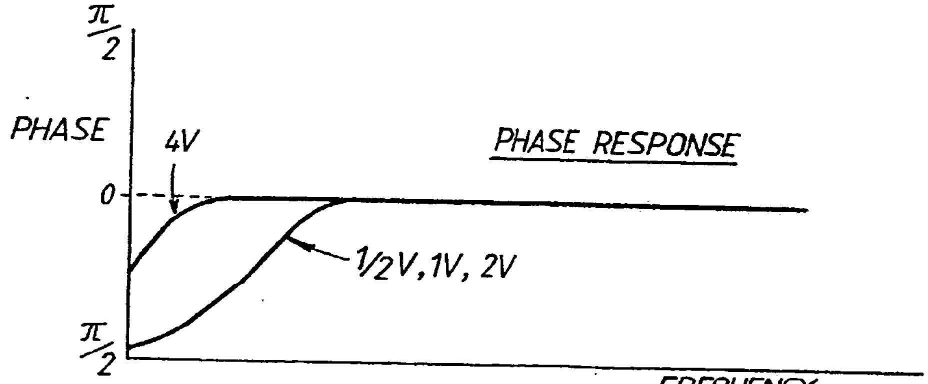

FIG. 3.

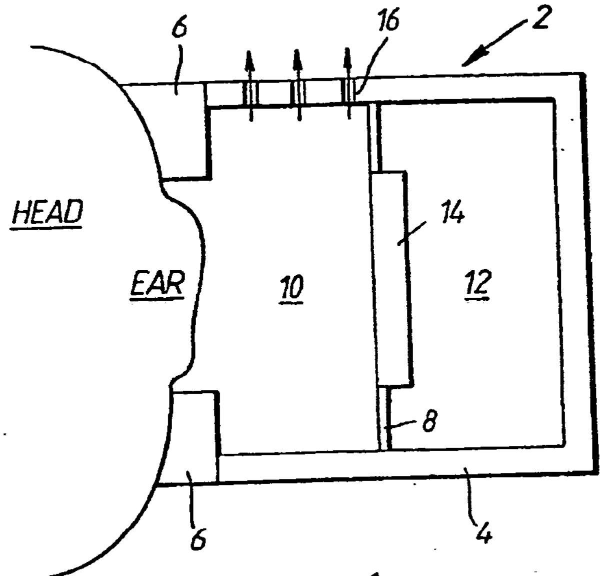

FIG. 4.

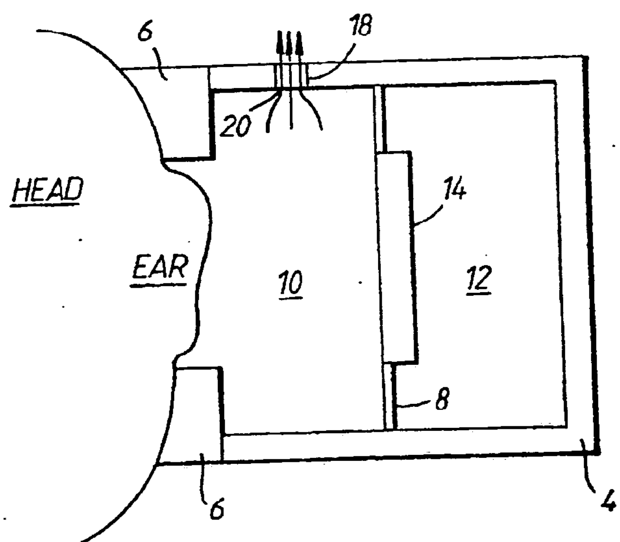

FIG. 5.